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ORIGINAL RESEARCH

THE RELATIONSHIP OF RANGE OF MOTION, HIP SHOULDER SEPARATION, AND PITCHING KINEMATICS

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ABSTRACT

Background: When pitching a baseball, pelvic and trunk pitching kinematics play an integral role in momentum transfer from the lower extremity to the upper extremity. However, it is unknown how hip and trunk ROM and hip shoulder separation interplay with pelvic and trunk pitching kinematics.

Hypothesis/Purpose: To determine the relationship between clinical trunk and hip range of motion (ROM) and pitching biomechanical pelvis and trunk kinematics, and kinematic sequencing.

Study Design: Controlled biomechanical study

Methods: High school pitchers were assessed for trunk rotation via motion capture and hip ROM via a goniometer prior to pitching. Trunk rotation was designated as dominant and non-dominant sides, and hips as stance and lead limbs. Pitchers threw four fastballs during three dimensional biomechanical assessment. Spearman's Rho correlations were performed between trunk and hip ROM, and trunk and hip biomechanical kinematics, and kinematic pitching sequence.

Results: Thirty-two pitchers (mean age: 16.3 ± 1.2 years, height = 184.0 ± 6.9 cm, mass = 76.8 ± 20.8 kg) were included in this study. Their mean pitch velocity was 34.7 ± 2.3 m/s, peak pelvis rotation velocity: 669.1 ± 95.5 deg/s, and peak trunk rotation velocity: 1084.7 ± 93.0 deg/s. There were no differences between dominant and non-dominant side trunk rotation, or between stance and lead hip ROM. There were no significant relationships between trunk or hip ROM and pitching kinematics. There was a significant relationship between hip shoulder separation and peak trunk rotation velocity ($r = 0.390$, $p = 0.027$). There was a significant relationship between pitch velocity and peak trunk rotation velocity ($r = 0.478$, $p = 0.006$). There were no other significant relationships between pitching kinematics or kinematic sequencing.

Conclusion: Hip shoulder separation is related to trunk rotation velocity, and ultimately pitch velocity. These ROM measurements can be used as normative values for hip shoulder separation in high school pitchers.

Level of Evidence: 3

Key Words: Biomechanics, baseball pitching, kinetics, fastball, trunk rotation Velocity, Movement System

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INTRODUCTION

Baseball injuries are prevalent, with injury incidence reported at up to 5.8 injuries per 1000 athlete exposures.[1] Of these injuries, the greatest number of injuries are attributed to the shoulder, elbow and trunk.[2] These injuries have been related to the high levels of force that occur during pitching,[3] which can result from limited range of motion (ROM) and poor pitching mechanics.[4-6] Accordingly, clinicians, scientists, and coaches have attempted to identify proper pitching mechanics and factors that influence these mechanics in order to attempt to reduce injury risk.[7-9]

The pitching motion is a complex movement that is initiated with the lower extremities and integrates the pelvis, trunk, arm, and hand to throw the baseball.[4] The pelvis and trunk serve as the link between the lower extremities and the upper extremity that allows momentum generated by the lower extremities to be translated to the upper extremity.[8,10] Appropriate and efficient proximal-to-distal kinematic timing between the pelvis and trunk allows for momentum transfer to the ball, and ultimately, increased pitching velocity.[11,12] If this kinematic sequencing is not optimal, energy is not appropriately transferred to the ball, and is dissipated into the upper extremity, potentially increasing injury risk.[11,13,14] For example, pitchers with early trunk rotation demonstrate greater shoulder joint forces compared to counterparts that initiated trunk rotation following front foot contact.[14]

Due to the importance of proximal pitching kinematics in relation to transferring momentum and the potential of undue upper extremity forces,[11,13-15] clinical and biomechanical assessments have been developed to assess these parameters.[16-18] Hip rotation ROM has been associated with pitching velocity in professional pitchers,[17] while trunk rotation ROM was found not to correlate to pitching velocity in collegiate pitchers.[18] A biomechanical variable that integrates both hip and trunk kinematics is hip shoulder separation (Figure 1). For a left-handed pitcher, hip shoulder separation is achieved at front foot contact as the hips rotate towards the plate, while the trunk remains facing first base. This constitutes the back (drive) leg externally rotating in order to allow the pelvis to rotate forwards towards home. This pitching biomechanical position integrates both hip and trunk ROM,[16] and has been observed to directly relate to pitching velocity[19] and fatigue.[16] However, hip shoulder separation has not been investigated in relation to clinical ROM assessment, nor in relation to pelvic and trunk kinematic sequencing.

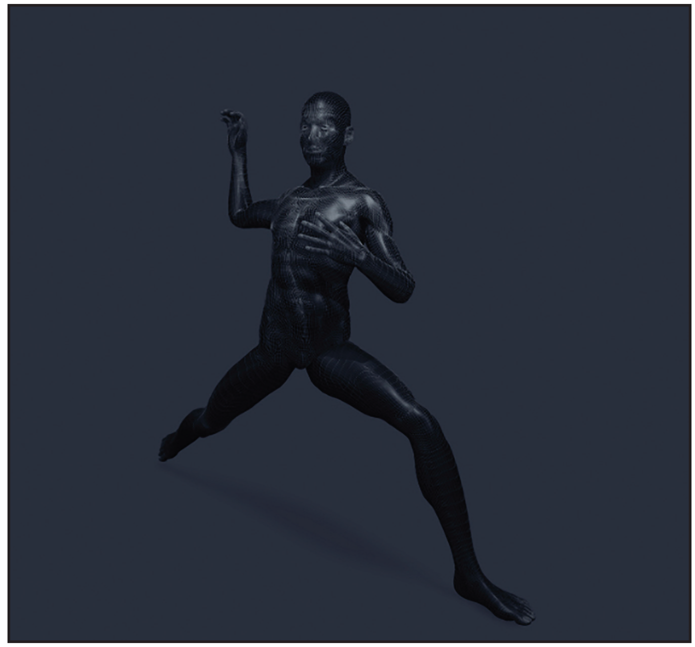

Figure 1. *Hip shoulder separation*

Pelvic and trunk pitching kinematics play an integral role in momentum transfer and in upper extremity force distribution.[8,12,19] However, it is unknown how hip and trunk ROM and hip shoulder separation interplay with pelvic and trunk pitching kinematics and kinematic sequencing. Understanding the association between clinical and biomechanical pitching assessments may assist clinicians, scientists, and coaches to develop effective interventions to affect pelvic and trunk pitching kinematics and ultimately injury risk and performance. Therefore, the purpose of this study was to determine the relationship between clinical trunk and hip ROM and pitching biomechanical pelvis and trunk kinematics, and kinematic sequencing.

METHODS

Experimental Approach to the Problem

In this retrospective review, data were examined from reports generated as part of this study which included a pitching evaluation. This study was approved by the Wake Forest University Institutional Review Board. Participant recruitment was performed through flyer and internet advertisement, phone calls to local and regional baseball organizations, and participant word of mouth. Prior to the pitching evaluation, participants were informed of the risk and benefits of participating in this study. If under 18 years old, all parents and/or guardians and participants gave informed consent to participate in this study. High school pitchers from regional high schools and baseball academies participated in a pitching evaluation at the Wake Forest Pitching Laboratory. Inclusion criteria consisted of the following: baseball athletes, any level of formal competition, self-identified pitcher as a primary or secondary position, and age 14 to 19 years old. Participants were able to participate in all training, practices, and competitions at initial testing. Participants were excluded if they reported pain during any testing, had undergone surgery in the past twelve months, or were not participating in all baseball related training, practices, or games. As part of the pitching evaluation, all pitchers had trunk and hip rotation measured, and completed a three-dimensional biomechanical evaluation. In order to have greater clinical and literature comparison, participants performed all range of motion testing prior to warm up and biomechanical pitching assessment.

Trunk Rotation

The trunk rotation measurement protocol used in this study has been validated and deemed reliable in healthy adults.[20] Trunk rotation was measured with the motion capture system. Subjects were instructed to sit on a standardized seat, with hips and knees flexed to 90 degrees. A test administrator placed a ball (21 cm diameter) between the knees of each athlete and instructed subjects to lightly squeeze the ball. Subjects were directed to maintain gaze direction at a point at eye level, while rotating to their maximum end range to one side. Right and left side rotation was performed three times and averaged across trials.[20] All subjects had markers on their left and right acromion processes of the shoulders, and on the left and right anterior superior iliac spines (ASIS). The angle between the vector from the right acromion process to the left acromion process and the vector from the right ASIS to the left ASIS was calculated. The local minimum and maximum values were identified as the maximum left and right trunk rotations, respectively (Figure 2). Trunk rotation was designated to dominant and non-dominant

Figure 2. *Trunk Rotation*

sides for analysis.[18] Trunk rotation difference was derived by subtracting the non-dominant side trunk rotation from dominant side trunk rotation. A negative number entails that the dominant side trunk rotation is greater than the non-dominant, while a positive number entails that the non-dominant side trunk rotation is greater than the dominant.

Hip Rotation

Participants were placed supine with the hip and knee flexed to 90 degrees.[21,22] Two test administrators performed testing procedures, one administrator held the limb in position, while the second administrator measured the testing limb. Both test administrators performed the same duty for all measurements.[23] A standardized bubble goniometer (Baseline Absolute Axis, Fabrication Enterprises Incorporated, White Plains, NY) was utilized for all measurements, with the stationary arm perpendicular to the long axis of the subject and the mobile arm parallel to the tibia (Figure 3). The test administrator took hip internal rotation (IR) and external rotation (ER) to a firm end feel without altering arthrokinematics.[23] Hip measurements included IR, ER, and total range of motion (TROM). Total ROM was derived by adding the values for hip IR and ER.[23] All hips were designated as *stance* and *lead* limbs. The *stance* limb was defined as the leg that coincided with the participant's throwing arm. The *lead* leg was defined as the limb contralateral to the throwing extremity.[24] The difference between hip IR, ER, and TROM was calculated by subtracting the *lead* limb from the stance limb. The hip ROM protocol has been found to be valid and have excellent reliability in healthy adults and subjects with hip pathology.[21,22] The standard error of measurement was observed to be 2.4 degrees for IR and 2.5 degrees for ER.[22]

Biomechanical Analysis

Three-dimensional motion data were collected using the 38 reflective marker set required for PitchTrak (Motion Analysis Corporation, Santa Rosa, California), and a sixteen-camera motion analysis system (Motion Analysis Corporation, Santa Rosa, California). Motion data were collected at 250 Hz. Pitchers threw from an indoor turf mound, the Perfect Mound (Porta-Pro Mounds Inc, Sauget, Illinois). The mound was engineered to meet major league specifications and covered with 4.4 cm (1¾ inch) infilled turf. Pitchers were allowed to wear their cleats. Ball velocity was recorded with a Trackman device (Trackman, Scottsdale, Arizona).

After completing clinical measures, each pitcher went through a pregame warm-up period of 15 minutes consisting of dynamic warm up and throwing to 36 m. To maintain pitching specific routines, the dynamic warm up and throwing count was not standardized. Following warm up, pitchers threw a series of four fastballs, four breaking balls, and four change ups to a catcher receiving throws at a regulation distance (18.4 m) or a target net behind a plate at regulation distance. Fastballs were thrown first. Due to each pitcher pitching a different selection of breaking balls (e.g. curveball or slider) and change-ups (e.g. circle changeup, split finger, or fork ball),

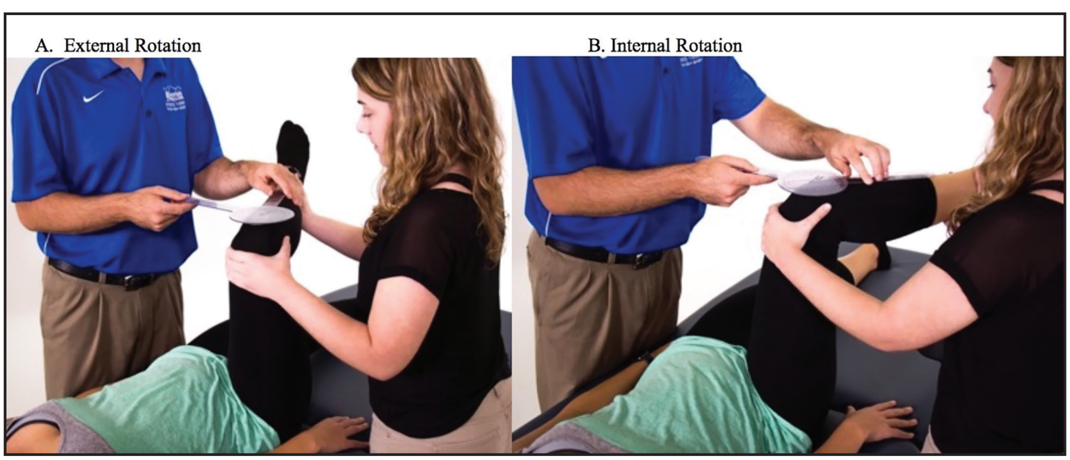

Figure 3. *Hip Rotation*

or only throwing two pitch types, only the fastball data were analyzed for this study. Data were processed and variables were calculated with Visual 3D (C-Motion, Inc. Germantown, Maryland). Variables extracted from the pitching reports included ball velocity, hip shoulder separation at foot contact, peak pelvis rotation velocity, peak trunk rotation velocity, time of peak pelvis rotation velocity, and time of peak trunk rotation velocity. Pitching models were defined using the PitchTrak model, and segment coordinate systems were defined according to ISB recommendations.[11,25] Hip shoulder separation was defined as the angle of rotation between the trunk and pelvis segments.

Statistical Analyses

An *a priori* analysis was performed with a β of 0.80, an α of 0.05 that determined a sample size of 15 was necessary to observe a moderate correlation of 0.30.[26] Prior to analyses, data were evaluated for normality. Data were observed to have a normal distribution for ROM data, excluding hip TROM and trunk rotation measurements. Data had a non-normal distribution for kinematic data. Data transformations were then attempted for kinematic data without success, resulting in utilizing non-parametric analyses. A series of t-tests and non-parametric Mann-Whitney U tests were performed to analyze the presence of a difference between dominant and non-dominant sides for all ROM data ($p < 0.05$). A series of non-parametric Spearman's Rho correlations were then performed to investigate the relationship between trunk and hip ROM, and trunk and hip biomechanical kinematics, and trunk and hip kinematic pitching sequence ($p < 0.05$). The current baseball biomechanical industry recommended threshold for hip shoulder separation is 55 degrees. In order to increase clinical utility, receiver operator curve (ROC) analyses were performed between the proposed hip shoulder separation threshold and trunk and hip ROM that exceeded a correlation of 0.20. An *a priori* area under the curve (AUC) of 0.70 was set for significance.[27] χ^2 analyses was performed to calculated odds ratios with 95% confidence intervals (95% CI) for all significant ROC curve analyses. All analyses were performed in R version 3.5.1 (R Core Team [2013]. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/). All range of motion and velocity averages are reported as degrees or degrees/second $\pm$ standard deviation (SD), unless otherwise stated.

RESULTS

A total of thirty-two high school baseball pitchers were included in the final analysis with a mean age, height, and weight of 16.3 $\pm$ 1.2 years, 184.0 $\pm$ 6.9 cm, and 76.8 $\pm$ 20.8 kg, respectively. Most of the pitchers (N = 23 [72%]) were right-hand dominant in terms of throwing and had played baseball for a mean of 11.5 + 1.6 years. A total of 25 participants identified as primarily a starting pitcher, and seven identified pitching as their second position. Trunk and hip range of motion averages are summarized in Table 1. Briefly, hip ER differences between stance and lead legs were –0.1 ± 11.0° ($p = 0.974$). Hip IR differences between stance and lead legs were 0.5 ± 6.1° ($p = 0.793$). Hip TROM differences between stance and lead legs were 0.4 ± 12.1° ($p = 0.748$). Trunk rotation differences between dominant and non-dominant sides were -2.8 ± 7.6° ($p = 0.238$). Mean pitch velocity was 34.7 ± 2.3 m/s. Peak pelvis rotation velocity was 669.1 ± 95.5 deg/s and peak trunk rotation velocity was 1084.7 ± 93.0 deg/s (Table 2).

Correlation analysis between trunk and hip range of motion, biomechanical kinematics, and kinematic pitching sequence

There were no significant relationships between hip shoulder separation and peak pelvic rotation velocity ($r = -0.349$, $p = 0.051$), time of peak pelvis rotation ($r = 0.155$, $p = 0.397$), time of peak trunk rotation ($r = -0.150$, $p = 0.412$), or the difference in time of peak trunk and pelvis rotation ($r = 0.045$, $p = 0.808$). There was a significant moderate relationship between hip shoulder separation and peak trunk rotation velocity ($r = 0.390$, $p = 0.027$) (Figure 4).

Furthermore, there were no significant relationships between pitch velocity and peak pelvis rotation velocity ($r = -0.026$, $p = 0.891$) or the difference in time of peak trunk and pelvis rotation ($r = 0.276$, $p = 0.126$). There was a significant moderate relationship between pitch velocity and peak trunk rotation velocity ($r = 0.478$, $p = 0.006$) (Figure 5).

Table 1. *Range of motion* and relationship to hip shoulder separation.*

	Mean ± SD	Spearman's Correlation	p-value
Stance Hip ER	43.8 ± 11.0	-0.11	0.535
Stance Hip IR	29.8 ± 8.1	-0.09	0.614
Stance Hip TROM	73.5 ± 14.0	-0.21	0.249
Lead Hip ER	43.8 ± 11.4	-0.07	0.693
Lead Hip IR	29.3 ± 7.9	-0.29	0.109
Lead Hip TROM	73.0 ± 15.2	-0.21	0.249
Hip ER Difference	-0.1 ± 11.0	-0.16	0.388
Hip IR Difference	0.5 ± 6.1	0.24	0.195
Hip TROM Difference	0.4 ± 12.1	-0.04	0.815
Dominant Side Trunk Rotation	61.0 ± 10.8	0.02	0.892
Non-dominant Trunk Rotation	63.8 ± 10.6	0.19	0.308
Trunk Rotation Difference	-2.8 ± 7.6	-0.09	0.622
Ratio of Dominant Side Trunk Rotation and Stance Hip ER	149 ± 47%	0.03	0.883
Ratio of Dominant Side Trunk Rotation and Stance Hip IR	236 ± 83%	0.08	0.654
Ratio of Non-dominant Side Trunk Rotation and Lead Hip ER	157 ± 54%	0.09	0.626
Ratio of Non-dominant Side Trunk Rotation and Lead Hip IR	236 ± 83%	0.30	0.093

* Reported in degrees
ER = External Rotation, IR = Internal Rotation, TROM = Total Range of Motion, SD = Standard Deviation

Table 2. *Pitching Kinematics and Kinematic Sequence.*

	Measure ± SD
Hip Shoulder Separation (in °)	48.4 ± 10.9
Peak Pelvis Rotation Velocity (in °/second)	669.1 ± 95.5
Peak Trunk Rotation Velocity (in °/second)	1084.7 ± 93.0
Peak Pelvis Rotation Time (in miliseconds)	782.1 ± 112.1
Peak Trunk Rotation Time (in miliseconds)	806.4 ± 98.6
Difference in Peak Trunk and Peak Pelvis Rotation Time (in milliseconds)	24.3 ± 24.3

SD = Standard Deviation

Receiver operator characteristics analyses between hip shoulder separation and hip and trunk range of motion

A total of 22 (69%) pitchers exhibited hip shoulder separation ≤ 55 degrees, and 10 (31%) pitchers displayed hip shoulder separation above 55 degrees. There was a relationship between the hip shoulder separation cut point and the difference between stance and lead hip IR (AUC = 0.78, p = 0.024). Pitchers with a hip difference of 4.3 degrees (95 CI: –0.8, 8.4) had a 1.23 (95% CI: 1.05, 1.50) greater odds of displaying greater than 55 degrees of hip shoulder separation. There was no relationship between the hip shoulder separation cut point and lead hip IR (AUC = 0.68, p = 0.105), non-dominant side trunk rotation (AUC = 0.55, p = 0.631), or the ratio between non-dominant trunk rotation and lead hip IR (AUC = 0.67, p = 0.202)

DISCUSSION

The main findings of the study were that there was a moderate association between hip shoulder separation at foot contact and peak trunk rotation velocity, as well as between pitch velocity and peak trunk

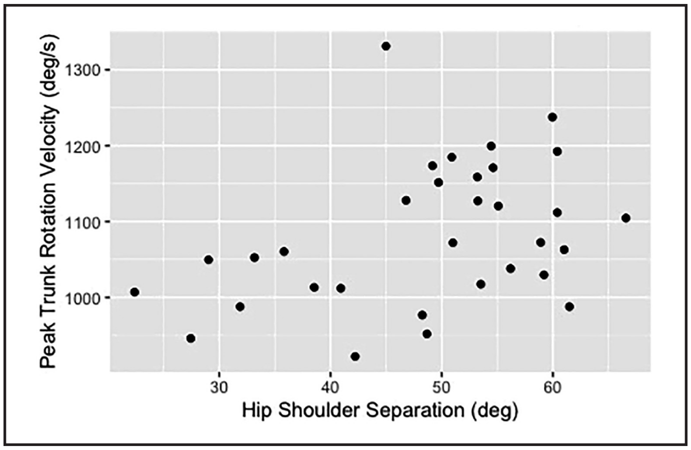

Figure 4. *The relationship between maximum hip shoulder separation and peak trunk rotation velocity*

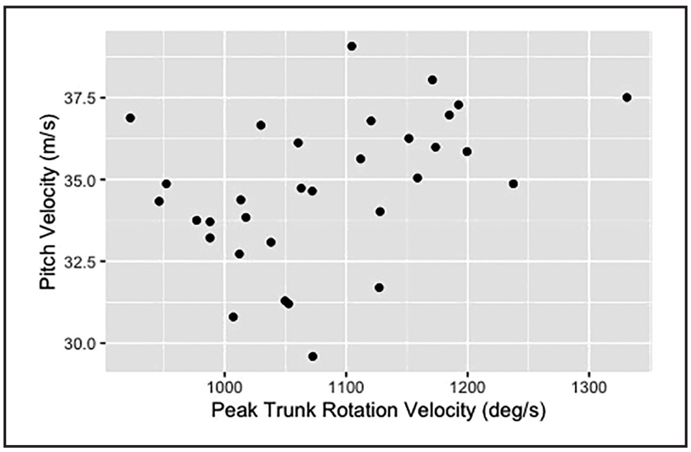

Figure 5. *The relationship between peak trunk rotation velocity and pitch velocity*

rotation velocity. However, there were no relationships between hip or trunk ROM and pitching kinematics nor pelvis and trunk kinematic sequencing and hip shoulder separation. These results have implications in sports performance, specifically the potential relationship of hip shoulder separation and the stretch shortening cycle, as previous studies have demonstrated that pelvic and trunk pitching kinematics play an important role in in pitch velocity, which has been shown to directly influence pitching performance.[8,12,19]

Maximum trunk rotation velocity was similar to previous studies, demonstrating similarity in baseball participants and biomechanical model structure.[8,28] However, this study reported hip shoulder separation in degrees, which is in contrast to previous studies that reported hip shoulder separation in percentage or only as a correlation to pitch velocity.[16,19] In this study, hip shoulder separation was reported in degrees to increase the clinical utility of these findings. Greater hip shoulder separation may allow for increased potential elastic energy to be retained prior to trunk rotation through the oblique stretch shortening cycle.[10,29] During pelvic rotation, the oblique musculature eccentrically contracts, followed by concentric muscular contraction during trunk rotation.[29] The greater hip shoulder separation may potentially allow improved oblique muscular eccentric contraction, permitting for greater torso rotation velocity.[16] Another potential explanation is that greater hip shoulder separation allows for a larger rotation arc through which the trunk can build rotational velocity. Within this study, there was no relationship between hip shoulder separation and time between maximum pelvic and trunk rotation velocity. In other words, trunk rotation requires a similar time to rotate during the pitching sequence, irrespective of the hip shoulder separation ROM. In the case of a larger rotational arc, the trunk then must rotate at a greater rotation velocity. Despite these theories, hip shoulder separation should be analyzed when assessing kinematic factors that can affect pitching motion efficiency.

The current study documents the moderate relationship between maximum trunk rotation velocity and pitch velocity, which supports previous research.[8,9] The trunk can provide up to 50% of kinetic energy and momentum during the pitching motion.[30] As a result, greater trunk rotation along the longitudinal axis allows for greater force transfer through the arm, and eventually to ball propulsion.[12,14] Increased trunk rotation velocity contributes to increased shoulder external rotation and shoulder hyperangulation,[14,28] which has been directly linked to increased pitching velocity.[31] As with the pitching stretch shortening cycle within the oblique musculature,[10,29] movement into shoulder external rotation eccentrically lengthens the shoulder internal rotators, providing greater elastic energy to utilize during the pitching acceleration phase.[31] The direct connection between trunk rotation and shoulder kinematics, and ultimately pitching velocity, demonstrates the relationship between proximal to distal pitching kinematics and momentum transfer.

Previous research in professional baseball players has demonstrated a moderate relationship to hip lead leg, hip TROM and pitch velocity, and decreased lead leg hip ROM in all ROM measurements compared to the stance leg.[17] Although in the current study there were no statistically significant associations between hip ROM and any pitching kinematics, or stance and lead leg hip ROM, these discrepancies could be attributed to the overall total volume of pitching in professional pitchers in comparison to high school pitchers.[32] Specific asymmetrical hip adaptations could develop through lead leg repetitive loading due to the lower extremity rotational stresses incurred during pitching.[7] Another possible explanation is the methodological differences in hip ROM measurement. While both studies utilized a goniometer, in this study, hip ROM was measured supine in comparison to prone.[17] Measuring hip ROM in supine decreases the hip flexor length tension relationship in comparison to prone, possibly altering hip ROM results.[33] There were also no associations between trunk ROM and pitching kinematic variables, nor were there ROM differences between dominant and non-dominant trunk rotation. These results support a previous study in which trunk ROM was not associated with pitching velocity.[18] Further, hip IR difference reported an AUC of 0.78, and a cut point of 4 degrees. Thus hip, trunk, and hip shoulder separation ROM data can be utilized as healthy normative values for high school pitchers when evaluating hip and trunk biomechanics, which includes hip shoulder separation. Previous literature proposes that passive ROM should be greater than active ROM.[34] While hip shoulder separation is difficult to quantify without 3D biomechanical evaluation, if a high school pitcher exhibits less hip and trunk ROM, smaller differences between stance and lead leg ROM, or a smaller ratio between hip and trunk ROM than these normative values, clinicians should be cautious of the pitcher's ability to produce adequate hip shoulder separation. As a result, further examination, potentially including biomechanical assessment, should be recommended. Further, the results demonstrate that increased hip shoulder separation should allow for increased trunk rotation velocity and increased pitch velocity. The current ROM results suggest that these pitchers are capable of achieving greater hip shoulder separation than demonstrated biomechanically. However, these pitchers may not have achieved maximal hip shoulder separation due to the exact timing and sequencing between hip, trunk, and shoulder acceleration during the pitching motion. While there was a 24.3 millisecond difference between peak pelvis and peak trunk velocities, previous literature proposes that trunk acceleration should not begin until after peak pelvis rotation.[11,12] While the instrumentation and models used within this study did not allow for analysis of the timing of the occurrences during the pitching sequence, timing and sequencing variables should be explored in future work.

Strengths and potential limitations

This study assessed clinical and pitching biomechanical variables, providing clinical and baseball specific context. Hip and trunk velocity and kinematic sequencing were assessed, allowing for increased interpretability of these findings. While the warm up time was standardized to 15 minutes, each participant performed an individual warm up, decreasing the repeatability of this study. Each pitch type was pitched in succession, which may have created an order effect. Only fastballs were assessed for this study. Other pitches may have slight differences in kinematic variables decreasing the generalizability of these results to pitches other than the fastball. Only high school pitchers were recruited for this study, who may be physical and pitching developing athletes, which diminishes the generalizability of these findings to other pitching populations.

Future research

The role of pelvis and trunk kinematics and pitch velocity has been elucidated,[8,10,14] however, there are currently no prospective studies investigating the interplay between hip and trunk ROM and hip and shoulder kinematics and injury risk. To this end, future research is required to understand how these variables change following injury or potentially contribute to injury. Understanding how hip and trunk ROM and proximal pitching kinematics relate to injury can assist clinicians and coaches in developing effective interventions. While proper proximal pitching kinematic sequencing has been established as an important pitching biomechanical variable,[8,11,14] an additional study is required to understand what factors affect pitching kinematic sequencing. Lastly, further research is required to understand if specific strength and conditioning and rehabilitation exercises can improve hip shoulder separation and hip shoulder kinematics and kinematic sequencing.

CONCLUSION

The results of this study demonstrated significant moderate associations between hip shoulder separation at foot contact and peak trunk rotation velocity and between pitch velocity and peak trunk rotation velocity. There were no associations between hip or trunk ROM and pelvis or trunk kinematics or kinematic sequencing. Hip shoulder separation can be used as a pitching biomechanical variable to help determine pitching motion detriments that can affect trunk rotation velocity, which in turn is related to pitching velocity. These hip, trunk, and hip shoulder separation ROM data can be utilized as healthy normative values for high school pitchers.

REFERENCES

1. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train.* 2007;42(2):311-319.
2. Posner M, Cameron KL, Wolf JM, Belmont Jr PJ, Owens BD. Epidemiology of major league baseball injuries. *Am J Sports Med.* 2011;39(8):1675-1691.
3. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech.* 1999;32(12):1371-1375.
4. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. *Am J Sports Med.* 2010;38(7):1368-1374.
5. Scher S, Anderson K, Weber N, Bajorek J, Rand K, Bey MJ. Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. *J Athl Train.* 2010;45(2):191-197.
6. Marlier M, Van Dyck D, Cardon G, De Bourdeaudhuij I, Babiak K, Willem A. Interrelation of sport participation, physical activity, social capital and mental health in disadvantaged communities: A SEM-analysis. *PloS one.* 2015;10(10):e0140196.
7. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med.* 1995;23(2):233-239.
8. Stodden DF, Fleisig GS, McLean SP, Lyman SL, Andrews JR. Relationship of pelvis and upper torso kinematics to pitched baseball velocity. *J Appl Biomech.* 2001;17(2):164-172.
9. Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. *Sports health.* 2009;1(4):314-320.
10. Fleisig GS, Hsu WK, Fortenbaugh D, Cordover A, Press JM. Trunk axial rotation in baseball pitching and batting. *Sports Biomech.* 2013;12(4):324-333.
11. Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *J Appl Biomech.* 2007;23(1):42-51.
12. Putnam CA. Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *J Biomech.* 1993;26:125-135.
13. Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. *Sports Med.* 1996;21(6):421-437.
14. Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. *Am J Sports Med.* 2014;42(9):2089-2094.
15. Huang Y-H, Wu T-Y, Learman KE, Tsai Y-S. A comparison of throwing kinematics between youth baseball players with and without a history of medial elbow pain. *Chin J Physiol.* 2010;53(3):160-166.
16. Erickson BJ, Sgori T, Chalmers PN, et al. The impact of fatigue on baseball pitching mechanics in adolescent male pitchers. *Arthroscopy.* 2016;32(5):762-771.
17. Robb AJ, Fleisig G, Wilk K, Macrina L, Bolt B, Pajaczkowski J. Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *Am J Sports Med.* 2010;38(12):2487-2493.
18. Bullock GS, Schmitt AC, Chasse PM, Little BA, Diehl LH, Butler RJ. The relationship between trunk rotation, upper quarter dynamic stability, and pitch velocity. *J Strength Cond Res.* 2018;32(1):261-266.
19. Sgroi T, Chalmers PN, Riff AJ, et al. Predictors of throwing velocity in youth and adolescent pitchers. *J Shoulder Elbow Surg.* 2015;24(9):1339-1345.
20. Johnson KD, Kim KM, Yu BK, Saliba SA, Grindstaff TL. Reliability of thoracic spine rotation range-of-motion measurements in healthy adults. *J Athl Train.* 2012;47(1):52-60.
21. Nussbaumer S, Leunig M, Glatthorn JF, Stauffacher S, Gerber H, Maffiuletti NA. Validity and test-retest

reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients. *BMC Musculoskelet Disord.* 2010;11:194.

22. Prather H, Harris-Hayes M, Hunt DM, Steger-May K, Mathew V, Clohisy JC. Reliability and agreement of hip range of motion and provocative physical examination tests in asymptomatic volunteers. *PM & R.* 2010;2(10):888-895.
23. Camp CL, Spiker AM, Zajac JM, et al. Decreased hip internal rotation increases the risk of back and abdominal muscle injuries in professional baseball players: Analysis of 258 player-seasons. *J Am Acad Orthop Surg.* 2018;26(9):e198-e206.
24. Garrison JC, Arnold A, Macko MJ, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate decreased balance compared to healthy controls. *J Orthop Sports Phys Ther.* 2013;43(10):752-758.
25. Wu G, Van der Helm FC, Veeger HD, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *J Biomech.* 2005;38(5):981-992.
26. Cohen J. *Statistical power analysis for the behavioral sciences.* Routledge; 2013.
27. Shanley E, Kissenberth MJ, Thigpen CA, et al. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. *J Shoulder Elbow Surg.* 2015;24(7):1005-1013.
28. Oliver GD, Keeley DW. Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball pitchers. *J Strength Cond Res.* 2010;24(12):3241-3246.
29. Young JL, Herring SA, Press JM, Casazza BA. The influence of the spine on the shoulder in the throwing athlete. *J Back Musculoskelet Rehabil.* 1996;7(1):5-17.
30. Toyoshima S, Hoshikawa T, Miyashita M, Oguri T. Contribution of the body parts to throwing performance. In: *Biomechanics IV.* Springer; 1974:169-174.
31. Matsuo T, Escamilla RF, Fleisig GS, Barrentine SW, Andrews JR. Comparison of kinematic and temporal parameters between different pitch velocity groups. *J Appl Biomech.* 2001;17(1):1-13.
32. Ellenbecker TS, Ellenbecker GA, Roetert EP, Silva RT, Keuter G, Sperling F. Descriptive profile of hip rotation range of motion in elite tennis players and professional baseball pitchers. *Am J Sports Med.* 2007;35(8):1371-1376.
33. Bierma-Zeinstra SM, Bohnen A, Ramlal R, Ridderikhoff J, Verhaar JA, Prins A. Comparison between two devices for measuring hip joint motions. *Clin Rehabil.* 1998;12(6):497-505.
34. Roberts JM, Wilson K. Effect of stretching duration on active and passive range of motion in the lower extremity. *Br J Sports Med.* 1999;33(4):259-263.